

Suitability of Rice Straw Lignin as Boiler Fuel

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According to the latest figures from the U.S. Department of Energy's Annual Energy Review (1), energy sources for utilities and nonutility power sources consisted of approximately 2.8% biomass. Most of the biomass being consumed as an energy source is municipal solid waste (MSW) landfill gas, other anaerobic digestion gases, and wood biomass. With the development of biomass utilization in the next 10 years, such as in gasification, cofiring with coal in large-scale utilities and small-scale industrial boilers, expanded landfill gas utilization, and biomass-to-ethanol technology, the energy production from biomass resources could rise to 10%. Most ethanol in the United States is made from corn, however; new technological advances will make it economical to produce ethanol from lignocellulosic biomass feedstocks, such as rice straw, wood residue, hybrid poplar or willow trees, MSW, corn stover, alfalfa, sugarcane bagasse, and switchgrass. Fermentation products derived from the biomass-to-ethanol process include lignin, which is a combustible organic material or biomass fuel. Lignin as a stand-alone or cofiring fuel with coal may be a low-cost fuel for energy production. Some utilities may even consider the colocation of a biomass-to-ethanol plant near coal boilers to use the lignin residue as a lost-cost fuel.

Biomass cofiring with coal produces combustion ash in the boiler that can behave differently than coal ash, with positive or negative impacts depending upon the type of biomass (2). Lignin biomass typically contains very high silicon content, moderate to low sulfur, and only minor amounts of alkali-alkaline-earth elements such as calcium, magnesium, and potassium (3). A major challenge of firing lignin is the unproven performance in combustion systems, especially with respect to ash formation and deposition. This paper characterizes the inorganic material in rice straw and rice straw lignin (RSL). An evaluation of the combustion characteristics of lignin is also described, with a view toward suitability as boiler fuel.

One RSL was produced by a two-stage acid hydrolysis process at the National Renewable Energy Laboratory (NREL) and the other from a similar process developed by BCI (BCIJEN). The NREL sample was slightly higher in carbon, nitrogen, and ash and half as concentrated in sulfur. Sulfur quantities in both samples are considerably higher by an order of 3–6 compared to the raw rice straw (0.12%). Chlorine contents for the NREL and BCIJEN RSLs were 180 and 200 ppm, respectively, an order of 20 times less than what is in the rice straw. Mineral forms in the RSLs were quantified using scanning electron microscopy and consisted of 68% and 53% quartz (SiO₂) in the BCIJEN and NREL, respectively. Gypsum or anhydrite (calcium sulfate) comprised 11% and 3%, respectively, of the BCIJEN and NREL RSLs. Other mineral forms were only of minor or trace quantity. Both RSLs were prepared from similar feedstock and differences in mineralogy are likely due to acidification and neutralization processes. Both RSLs had calcium contents that were 5 times higher than the raw rice straw (2.0%).

The lignin samples were combusted in a drop-tube furnace under conditions similar to a utility boiler and evaluated for slagging and fouling propensity. Tests were conducted for 1.5 to 2 hours with feed rates averaging 0.12 g/min and residence times close to 4 seconds. The deposit collection zone was held at a constant temperature of 1000°C (1832°F), while the temperature in the upper zones of the furnace was held at 1380°C (2516°F). The deposits had similar growth factors and low deposit strengths, which were also considerably less than those values for a moderately fouling Black Thunder low-rank subbituminous coal. The major phases found in each ash and deposits were quartz and calcium silicate. The calcium silicate is formed as a result of a reaction between calcium (from lime neutralization during the ethanol processing) and silicon residue from phytoliths in the rice straw. The reaction is optimal when temperatures reach 1000°C (1832°F) and excess silicon is present. Sulfur is released by the thermal decomposition of gypsum and may or may not recombine with ash as it moves through the combustion environment.

The BCIJEN deposit was higher in silicon and lower in calcium than the NREL deposit. The NREL deposit is also higher in chlorine and sulfur, indicating the potential for a “stickier” deposit. One explanation may be that sulfur vaporized from NREL lignin is absorbed by available calcium in the ash; therefore, more sulfur is concentrated in the ash. The calcium in the ash created from the BCIJEN lignin is tied up more as a calcium silicate and is not available to react with sulfur; consequently, sulfur remains in the gas phase.

An attempt was made to provide a predictive tool for future fuel evaluation. Bulk ash viscosities were calculated from the fuel chemistries of the two lignin samples and a coal from the Black Thunder Mine at an array of temperatures expected in slagging and fouling regimes of a coal boiler. The viscosity curves show significantly higher viscosities for the RSL fouling deposits compared to the Black Thunder coal deposits and slightly higher slagging deposit values. Lower viscosity generally indicates stickier material and greater sintering potential for stronger deposits. In addition, a series of fouling indices that were developed for coal at the EERC also showed lower fouling potential for the RSLs in higher-temperature reheater regions of a boiler, but slightly higher potential in the lower-temperature economizer or air heater regions of a boiler. These predictive tools verify the combustion testing data that showed weak deposits and low “sticking” potential in higher-temperature fouling zones. The relatively higher low-temperature fouling potential is attributed to the higher Ca and S, high silica content, and fine particles in the lignin ash samples.

Rice straw lignin has excellent potential as a renewable biomass fuel source for energy production in utility or small industrial boilers. Lignin-derived ash deposits consisted of mostly calcium and silicate phases. Silica originates from phytoliths in the raw rice straw, while the calcium is added in the ethanol processing. Performance indices and viscosity curves calculated from deposit chemistry show significantly lower fouling for the RSL compared to a moderately fouling coal. Fine-sized ash particulate was generated for the RSLs which may need some attention with respect to particulate control and low-temperature fouling, especially if the material is cofired with coal.

References

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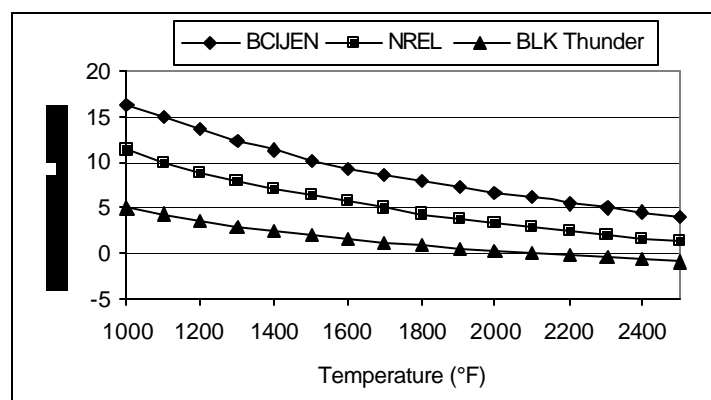


Figure 1. Predicted ash deposit liquid-phase viscosity curves for RSL and coal.